

Using μ CT to investigate water migration during freeze-thaw experiments

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1. Introduction

The degree of water saturation is an important factor to freeze-thaw (FT) weathering. There is even a material-specific critical saturation level above which the host will suffer immediate damage when subjected to a FT cycle (Prick, 1997). Up to today, it is not fully clear which process, accompanying crystallization in the pores, is responsible for the stress build-up. Hence, the link between the pressure mechanism and the critical saturation degree is not fully understood. It is believed moisture is drawn towards growing crystals (Everett, 1961; Walder and Hallet, 1985), which enables the crystals to remain growing as long as water is able to move to the site. Consequently, crystallization pressure on the pore walls is supposed to be the main damaging mechanism (Scherer, 1999). However, in highly saturated rocks, there could be an influence of trapped water in the smaller pores of the system, and hydraulic pressures could be generated (e.g. Powers, 1945) for high rates of freezing and low permeabilities. However, the latter is unlikely to occur within *in situ* building materials (Scherer and Valenza, 2005). These theories can be supported by measuring the length change of samples subject to a FT experiment. However, such observations only result in indirect evidence which could lead to misinterpretations (e.g. Powers & Helmuth, 1953). Therefore, *in situ* monitoring water transport during one or more FT-cycles, could deliver an extra clue in the search for the damaging mechanisms. Cyclic FT weathering tests were performed both on laboratory scale and on the micro-scale using X-ray computed tomography (μ CT) on samples with different degrees of saturation. Laboratory samples were monitored for length changes and long-term decay pattern. μ CT time-lapse imaging of the freezing process, was used to study the repositioning of water/ice. Afterwards, these microscopic observations were compared with the macroscopic weathering pattern, with a link to the saturation degree.

2. Materials and Methods

Savonnières limestone (Upper Jurassic) is a French natural building stone composed of oolites and shell fragments. Bentheimer sandstone (Lower Cretaceous) is found at the German-Dutch border and is a well-sorted, homogeneous quartz arenite. FT resistivity largely depends on the pore characteristics of a certain material. Therefore, these two stones, which are known to have totally different pore characteristics, were selected for the experiments.

The weathering behaviour of the two natural stones was investigated in function of the degree of water saturation. After applying 140 FT cycles to differently saturated samples, the damage was assessed visually, microscopically and by porosity measurements. Monitoring some proxies of the internal processes during the FT cycles (i.e. temperature evolution and length change) were added to comprehend the internal processes.

To assess the processes within the pores, μ CT was used. This technique has proven its value within geoscience as a non-destructive imaging method (Cnudde and Boone, 2013). At the Ghent University Centre for Tomography (UGCT) it has been possible to image a sample subjected to FT cycles (De Kock et al., 2015) by implementing a custom-made freezing stage (De Schryver et al., 2014). To check the feasibility of the technique and the duration of an appropriate FT process, a Savonnières sample was imaged at several defined temperatures during cooling. To investigate the preferred location of water/ice crystals and whether these locations shift during the process, samples with certain defined saturations were subjected to FT cycles on the μ CT device. The samples of interest were imaged both unfrozen and frozen and this for several FT cycles.

3. Results and discussion

Results of the weathering test show that Bentheimer sandstone and Savonnières limestone have a different weathering pattern, independent of the saturation degree. At saturation degrees larger than 80 %, Bentheimer will burst from the inside out, while Savonnières will lose large parts of its edges. At lower saturation degrees, both stones remain unaffected after 140 FT cycles.

An exotherm in temperature measurements during FT cycles shows that crystallization does occur in all samples when cooled to -15 °C. Similar to the temperature, length change curves illustrate the crystallization event. For low saturations, the length change curve follows the temperature curve, while for high saturations, it is clear that more stress is developed within the pores. The way this is pronounced is however slightly different for both stones. Both, temperature and length change curve indicate a different effect of processes in the pores for both stones while a similar FT test is performed.

A first μ CT test on a Savonnières sample shows that it is possible to monitor the change between the unfrozen and frozen scan (Fig. 1). When the behaviour of the pore water/ice is monitored after several cycles, a shift is seen in the positions of the ice. Combining the results of μ CT with the proxies for ice crystallization could lead to a more uniform idea of what happens during ice crystallization and melting within these rocks and what the influence of the saturation degree is on the acting processes.

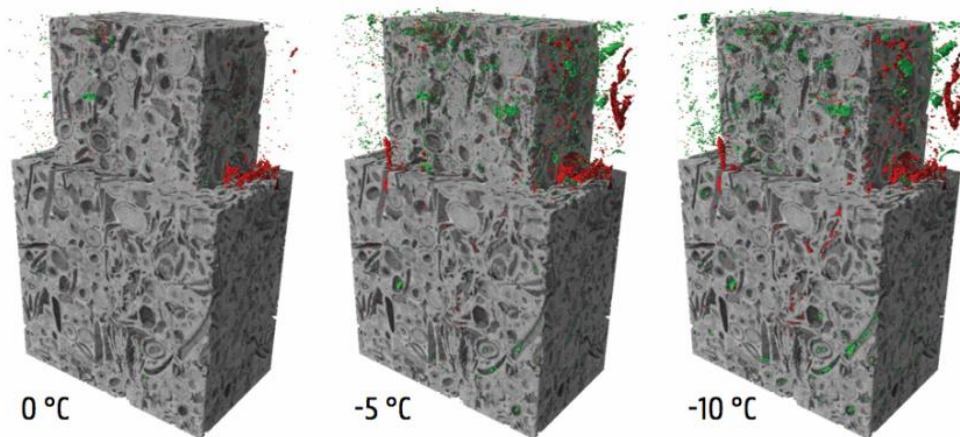


Fig. 1: Cropped 3D representation of a Savonnières sample during a freezing process. The red coloured volumes represent areas where mass has disappeared, while addition of mass is coloured green. These coloured areas therefore indicate wherefrom water was drawn and where it was transported during freezing respectively.

4. References

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